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UNITED STATES INVESTIGATIONS TO EVALUATE THE POTENTIAL THREAT OF STRATOSPHERIC OZONE DIMINUTION

Presented by
The United States of America

U.S. INVESTIGATIONS TO EVALUATE THE POTENTIAL THREAT OF STRATOSPHERIC OZONE DIMINUTION

For presentation at
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1. History of United States Concern Relating to the Earth's Ozone Concentration

Currently the United States is engaged, together with a number of other nations, in a large research effort related to the problem of assessing the impact of human activities on the earth's stratospheric ozone concentration and the resulting effects of ozone diminution on earth. This research effort involves many hundreds of participants in governmental, industrial, academic and other non-profit institutions and includes many activities undertaken internationally, either in collaboration with national science organizations in individual countries or in the framework of international scientific organizations.

U.S. investigations have focused in succession on several specific areas of human activities which tend to increase the supply of ozone-destroying substances in the stratosphere over and above the natural processes of ozone creation and destruction. These include:

- Aircraft engine emissions in the stratosphere or upper troposphere.
- Release of chlorofluoromethanes in the atmosphere.
- Release of nitrous oxide in the atmosphere.

The United States' studies to a large extent have been directed toward specific issues of potential adverse affects in the stratosphere. However, there is increasing recognition of the importance of stratospheric modification as a long-term problem whose implications and dimensions are not very well known.

As many of the impacts of human activities on the stratosphere involve long incubation periods by human time scales, measured in decades or longer, and even longer recovery periods, nations individually and collectively must learn how to anticipate, to study, to prevent where possible, and to cope with when necessary, the full dimensions of this problem. This will require a long-term program of continued research and cooperative international effort, not only into atmospheric physics and chemistry, but also biological, ecological, agricultural and climatic research and critical examination of the many difficult economic, social, political and legal questions.

The U.S. Congress has devoted particularly close attention to the full dimensions of the scientific concerns that the scale of aerospace, industrial and agricultural operations were potentially threatening to modify the radiative properties of the atmosphere. In 1971 Congress directed that a Climatic Impact Assessment Program (CIAP) be undertaken to study and provide within four years a report to Congress on the possible effects of high-altitude aircraft on the ozone layer. The CIAP Report, completed in 1975, concluded that there is cause for concern from the operation of large fleets of civilian high-altitude aircraft in or near the stratosphere using currently available aircraft engine technology.

In 1975, the U.S. National Academy of Sciences, in a report prepared with governmental funding, reviewed the conclusions of the CIAP study, and reaffirmed that there was cause for national and international concern from the reduction of the amount of ozone in the stratosphere. The National Academy's Climatic Impact Committee, recognizing the stratosphere is a world resource that knows no boundaries, recommended that "international organizations concerned with atmospheric science, biological science, medical science and aerospace science devote increased attention to studies concerned with the stratosphere and with possible inadvertent modification thereof".

Interest in chlorine chemistry in the stratosphere accelerated rapidly in 1974 with regard to the effects of chlorofluoromethanes in the atmosphere, following the work of Rowland and Molina, Cicerone and Stolarski, McElroy and Wofsy and others. At that time the fluorocarbon research program of the Manufacturing Chemists Association was redirected to emphasize stratospheric processes.

The U.S. strategy for a long-range, comprehensive program of research into the phenomena of the stratosphere and potentially adverse effects of inadvertent modification of the stratosphere has evolved from a June 1975 report of the Interagency Task Force on Inadvertent Modification of the Stratosphere (IMOS), a February 1976 report of its Subcommittee on Biological and Climatic Effects Research (BACER),

a second report by the U.S. National Academy of Sciences first issued in 1976, and the expressed policy of the U.S. Congress, which in 1976 further authorized and directed that a long-term, comprehensive program of research be undertaken of the phenomena of the upper atmosphere "so as to provide for an understanding of and to maintain the chemical and physical integrity of the Earth's upper atmosphere".

The U.S. long-term research plan, now under preparation, has as its goal the development of a better understanding of the physics and chemistry of the stratosphere, the extent to which a resulting increase in the amount of solar ultraviolet radiation may adversely modify the biological balance of the planet, the incidence of radiation-caused skin cancer, and the Earth's climate, and study of associated economic, political, social and legal problems in the national and international sphere. The research plan will define a research program that builds on and extends the current assessments of the impacts of aircraft engine emissions, chlorofluoromethanes and other chlorinated compounds, and nitrogen fertilizers; that extends the detailed analyses of the Climatic Impact Assessment Program; that coordinates the research techniques of the space age, using satellites and the U.S. Space Shuttle as well as airborne, rocket and balloon platforms, and that applies modern medical and biological sciences using advanced statistical methods and probing at the cellular and molecular levels for an understanding of effects mechanisms.

2. Investigations of Atmospheric Properties and Processes

2.1 Field Measurements and Monitoring

United States investigations of the fragile nature of the earth's ozone shield have included the exploration of the principal source and sink terms and linking atomic and molecular species of the major photochemical systems; monitoring ozone on a global scale; monitoring of solar radiation; determination of stratospheric circulation; aerosol size distribution, composition and number density; and atomic oxygen concentration in the stratosphere. Only a few of the necessary measurements have been made to date. Simultaneous measurements are required of one or more of the radicals in each of the nitrogen, hydrogen, and chlorine systems, and of hydroxyl radical, atomic oxygen, and excited oxygen atoms, which play major roles in each system. Unfortunately, all the necessary instrumentation and measuring techniques, especially for simultaneous measurements, essential in order to fully understand the physics and chemistry of the atmosphere, have not been adequately developed at the present time.

Platforms for field measurements include balloons, sounding rockets, aircraft and satellites, each of which has its own unique capabilities. Ground-based instruments also play an important role in stratospheric measurements. The United States operates an extensive ground-based network for measurement of some of the stratospheric species, including ozone, carbon dioxide, aerosols, and at some stations, oxides of nitrogen, sulfur dioxide, and solar ultraviolet radiation.

Measurements were made under the CIAP program of the following stratospheric characteristics between 1971 and 1975: ozone, vertical temperature profiles, water vapor, oxides of nitrogen, methane (CH_4), nitric acid (HNO_3) carbon dioxide, oxides of sulfur, hydroxyl radical (OH), solar UV flux, and aerosols. In the troposphere, measurements were made of the vertical temperature profile, ozone, aerosols, CH_4, NH_4, chlorofluorocarbons, oxides of nitrogen, SO_4, total solar radiation and UV flux from 280 to 320 nm. Data from these measurements were employed in the development and use of several models of one, two, or three dimensions (1-D, 2-D, or 3-D).

The current program of field measurements continues those initiated during CIAP, with increased emphasis on the chlorine system (Cl, ClO_x) and its sources, particularly trichlorofluoromethane (F-11) ($CFCl_3$) and dichlorodifluoromethane (F-12) (CF_2Cl_2), and its sinks (hydrogen chloride, HCl), methane, carbon tetrachloride, radicals of the hydrogen system, especially OH, the nitrogen system (NO, NO_2, N_2O, N_2O_5) and the compounds intermediate between systems, such as chlorine nitrate, nitric acid.

Satellite instruments now include some to measure ozone on Nimbus 4 and Atmospheric Explorer E, vertical temperature profile on the NOAA operational environmental satellites, and solar flux, temperature, ozone and water vapor on Nimbus 6. Future satellite instruments on the Nimbus G will measure ozone, nitric acid, nitrogen dioxide, nitrous and nitric oxide, water vapor, methane, carbon monoxide, aerosols and solar flux.

Monitoring of the total ozone column in the United States was introduced on a systematic basis in 1957 as part of the International Geophysical Year activities. Currently the United States operates eleven Dobson spectrophotometer stations as part of the World Meteorological Organization's network of ground-based ozone stations. Data from the U.S. Dobson stations are checked for quality and then forwarded monthly to the World Ozone Data Center in Canada.

Direct measurements of the vertical profile of ozone were conducted in the United States through two major balloon sounding networks totalling 25 stations. Soundings were taken weekly from 1963 through 1966. Today routine weekly ozone balloon soundings are made at only a single station (Wallops Island, Virginia).

Rocket ozonesondes were developed during the 1960's to study the photochemical region from 25 to 60 km. Rocketsondes have been used primarily for special purposes such as short-term latitudinal surveys, satellite calibration, and the development of an ozone climatology. Currently, monthly soundings are conducted at only a single station (Wallops Island, Virginia). It is planned to add another rocket ozonesonde station at Fort Churchill in February 1977.

Satellite measurements of ozone, which offer the unique capability of global measurements from the same instrument, have been conducted systematically by two methods, backscattered solar ultraviolet (BUV) radiation and thermal emission in the infrared band of ozone. The BUV instrument was flown on the Nimbus 4 satellite from 1970 to date, and on the Atmospheric Explorer E from late 1975 to the present. The Limb

Radiance Infrared Radiometer (LRIR) was flown on Nimbus 6, providing data for only the six months lifetime of this cryostatted system.

The largest set of satellite ozone data is therefore that obtained by the BUV instrument. These data are currently being reduced and it is planned that the entire body of data will be made available to the scientific community by the end of 1978. Both high level profiles and total ozone column can be retrieved from these data. The data were acquired at approximately local noon time.

Recent work in statistical time series modeling by Hill, Sheldon and Tiede appears to provide a promising technique for the detection and early warning of significant trend changes from a globally representative sample of ozone stations.

2.2 Laboratory Measurements

Laboratory experiments have provided significant contributions to the understanding of stratospheric properties and processes in photochemistry, reaction rates, formation and properties of aerosols, heterogeneous reactions, and temperature and pressure dependence studies.

In 1975, the U.S. National Bureau of Standards published Chemical Kinetic and Photochemical Data for Modeling Atmospheric Chemistry. Since then, some of the uncertainties in reaction rates are being further refined. However, much remains to be done with respect to very reactive species under stratospheric conditions, such as measuring reaction rates for OH and HO_2 and several other significant reactive species. New measurement techniques are needed, which should lead to the development of instruments with the sensitivity needed for stratospheric measurements in the chlorine, nitrogen, and hydrogen systems. For example, there are at present very limited methods for measurement of several stratospheric constituents, including OH, HCl, ClO, $ClONO_2$, O, and HF. Instrument improvements and new developments are required for the accurate measurement of many species. Recent laboratory measurements have studied atom- or radical-molecule reactions over wide ranges of temperature. The best experimental results may show reproducibility of 15 percent and accuracy of ±10 to 20 percent within one study as well as agreement to ±20 to 30 percent between different studies which may employ substantially different techniques.

2.3 Modeling and Analysis

Much of the current knowledge about the chemical structure and the coupling processes of the stratosphere has been derived from a specific type of mathematical model, the one-dimensional (1-D) model. By explicitly treating only vertical transport and vertical concentration distribution of the trace species in the model atmosphere, the 1-D model is able to include explicit treatment of a large number (50 to 100) of chemical reactions. The vertical transport coefficient employed--the so-called "eddy diffusion coefficient"--is an empirical prescription derived from observations of the net vertical transport of a long-lived species such as methane or carbon-14. As such, it can be argued that the effects of the two horizontal axes have crudely been accounted for. In fact, the major justification for the applicability of such models is that they appear to reasonably well represent atmospheric behavior, though actual "validation" of the models' accuracy is rendered impossible at present owing to a lack of accurate data with which to make a precise experimental comparison.

General-circulation models (GCM) of the atmosphere represent the opposite extreme; they explicitly treat all three dimensions of motion, as nearly as possible, on the basis of physical principles of thermodynamics and fluid mechanics. The detailed representation of transport in these models makes it impractical at present, within existing limits or computer capacity, to treat explicitly a very large number of chemical reactions therein. The complexity and cost of development and use of such models also explains why perhaps only a handful of research groups in the world are actively pursuing their development.

An attractive compromise is, conceptually, a two-dimensional (2-D) model, which treats transport less completely than a GCM, but more realistically than a 1-D model, and treats chemistry more completely than a GCM but contains fewer chemical reactions than the 1-D models. "Validation" of the accuracy of the chemical system's representation by a 2-D model may be attained by comparison and test with results from a 1-D model. Validation of the 2-D model's transport parameterization--motion along longitude is treated explicitly while zonal symmetry is assumed--is more difficult, however. At present, the 2-D models have relied upon comparison of transport results with data obtained on the transport of radioactive debris, or comparison of observed and calculated trace species distributions. The lack of a good data base presents the same difficulties for this type as for the 1-D model. In particular, the small amount of data available at altitudes in excess of about 20 km makes meaningful validation of transport representative of 2-D models above that altitude difficult.

In the study of various possible anthropogenic effects on ozone, the choice of model must be considered in light of the problem under investigation. Thus, 1-D models prove quite satisfactory for assessments of the effects of CFM's upon ozone. Diurnal effects are difficult to treat accurately, it is true, as are spatial inhomogeneities in species concentrations for a 1-D model. It appears, however, that such effects are relatively small, and can be satisfactorily approximated so that the overall reliability of the 1-D model is quite high for the CFM problem. For

the aviation problem on the other hand large uncertainties are injected, even on the conceptual level, for studies which employ 1-D models. This situation arises because aircraft exhaust contaminants are injected directly into the 10 to 20 km region of the atmosphere, where transport processes are most poorly represented by the 1-D parameterization. Accordingly, uncertainties up to a factor of three arise from the fact that different fractional amounts of aircraft emission may be diffused upward to the vicinity of the ozone layer.

Studies in the United States, then, emphasize the importance of transport parameterizations much more strongly for studies involving aircraft and space shuttle emissions than those involving CFM's, and nitrogen fertilizers. As a result, considerable effort is being expended on more realistic representation of transport for aircraft emissions, employing 2-D and 3-D models.

2.4 Emission Inventory

Information on the production of halocarbons in the United States is available from U.S. Tariff Commission Reports. World production figures are harder to obtain in general, and are not available at all for the countries of eastern Europe. An attempt to assemble worldwide data was made first by the DuPont Company in view of the intense interest concerning chlorofluoromethanes.

In December 1975 results of three further studies and a joint U.S.-Canadian report to the OECD became available and provided a more accurate and detailed picture. Production estimates for the principal halocarbons in 1973 have been summarized from these sources. For the

two chlorofluoromethanes of most concern, they show a 1973 world production of $CFCl_3$ (F-11) as 368,000 metric tons/year, with the United States producing 45 percent of the world total; and for CF_2Cl_2(F-12) as 441,000 metric tons per year, with the United States producing 55 percent of the world total.

Figures for the total worldwide production and release into the stratosphere of F-11 ($CFCl_3$) and F-12 (CF_2Cl_2) to the present have been gathered by the Manufacturing Chemists Association for the period of manufacture up to 1958 and year by year from 1958 through 1975. The total produced in the world for F-11 comes to 3.44 million metric tons, and for F-12, to 5.09 million metric tons, almost all of this in the Northern Hemisphere. Of the total produced, it is estimated that 2.93 million metric tons of F-11 have been released to the atmosphere (85 percent) and 4.41 million metric tons of F-12 (87 percent).

For F-11, the data correspond to a worldwide growth rate of 13.9 percent per year for the period 1965-74, with a doubling time of 5.3 years. The corresponding data for F-12 are a worldwide growth rate of 9.9 percent per year, with a doubling time of 7.4 years. Production of both F-11 and F-12 apparently peaked in 1973-74, with a reported decline of 15 percent in 1975.

Studies of the global nitrogen system have just begun, and estimates of nitrogen and oxides of nitrogen sources by different investigators are still too divergent to indicate the direction of any conclusions.

2.5. Present Status of Stratospheric Investigations

In summary, one may say that to date true globally averaged profiles for the significant stratospheric parameters involved in the creation and destruction of ozone, as well as that for ozone, are not available. Average vertical profiles of various trace gases have been obtained at a few latitudes, and in some cases at a single latitude. It requires some judgement to estimate how well these profiles are representative of a true global average. Probably for the longer-lived trace gases the global mean profiles will not deviate significantly from the ones measured so far. Concentrations of the shorter-lived constituents strongly depend on a number of parameters and vary considerably in the stratosphere, both in time and space. So little is known about reactive species such as atomic oxygen, HO and HO_2 radicals and ClO that even single isolated measurements must be regarded as important.

Thus, the data available from field measurements and experimental laboratory studies define certain guidelines or broad bandwidth data from which the modeled profiles cannot deviate too much. Nevertheless, since the 1-D models which have been the primary tools for arriving at overall estimates of ozone depletion incorporate a vertical diffusion coefficient which has been empirically adjusted to a best fit with an assumed global mean profile for specific trace constituents, such as methane, interpretation of the results requires an understanding of both possible observational variabilities and model limitations.

With an understanding of the limitations of current 1-D models, it is possible to quantitatively estimate the steady-state reduction of ozone, based on explicit consideration of from 50 to 100

chemical reactions, including sources, sinks and interaction among the major systems, the "self-healing" feature of the stratosphere in face of ozone reduction, and various other considerations. The tentative conclusion of the National Academy of Sciences, based on data available and current understanding, is that the release of chlorofluoromethanes at the 1973 production rates will reduce the ozone balance at steady state by about 7 percent, with an uncertainty range of from 2 to 20 percent. Considerably more research on stratospheric properties and processes is needed over the next decade.

Aircraft engine emissions are primarily found in the transport-dominated lower stratosphere. A fuller consideration of the influence of transport on the distribution and concentration of oxides of nitrogen and other engine emissions will require 2-D and 3-D models. Multidimensional models also provide better understanding of many stratospheric processes and their development is a priority requirement.

Further research is needed to arrive at verifiable conclusions concerning the perturbation of the ozone balance to be expected from the increase of N_2O production from denitrification of nitrogen fertilizers. However, it has been assumed that each intervention in the stratosphere tending to increase the concentration of ozone-destroying radicals is linearly additive in contributing to eventual ozone reduction.

3. Possible Effects of Ozone Diminution on the Biosphere

Stratospheric ozone prevents most of the solar UV radiation at wavelengths below 310 nm from reaching the earth's surface. Decreasing amounts of stratospheric ozone will permit increasing amounts of harmful UV-B radiation (280-320 nm) to reach the earth's surface. Therefore, it is extremely important to understand, in a quantitative manner, the direct effects of increased UV-B flux to life on earth and indirectly through climate change which in turn affects life. The United States is conducting a multi-agency Biological and Climatic Effects Research Program (BACER) to produce needed knowledge in order to arrive at proper policy and regulatory decisions for the protection of human health and the biosphere, which in this case means protecting the stratosphere from human activities which may modify the stratosphere.

The program is designed to accomplish the following:

- o Greatly expand the data base for more accurate estimates of known effects (e.g., skin cancer incidence rates and correlations).
- o determine whether a number of suggested biological effects are of significance and to what degree.
- o significantly improve estimates of the quantitative effects on key biological species (e.g., agricultural crops, selected native species and aquatic organisms) and provide estimates of how near such species are to their limits of tolerance for increased UV radiation or other related environmental changes.

- initiate a number of basic investigations on cellular/molecular mechanisms in order to understand the interactions of UV-B radiation with living matter and to identify physiological "indicators" or "predictors" of UV sensitivity in humans, other animals or plants.

The principal objective for the first phase of the program is by December 1977 to decrease uncertainties in existing scientific knowledge and investigate new potential problem areas.

The long-term BACER program has plans for conducting supporting studies with plants, animals, and other organisms as well as studies at the molecular and cellular levels to understand UV damage and repair mechanisms and determine indicators of effects.

Topical areas of BACER programs are health effects, biological (nonhuman) effects, climatic effects, instrumentation and monitoring, and economic assessment.

3.1 Possible Effects of Increased UV-B on Human Health

Studies are being conducted to more accurately quantify the relationship between skin cancer incidence and UV-B radiation dose which has been demonstrated by available evidence from epidemiological studies and some laboratory studies. A worldwide increase in UV-B radiation flux can be expected to increase skin cancer incidence. The biological amplification factor (ratio of change in skin cancer incidence to change in UV-B flux) is judged by various investigators to be in the range from approximately unity to about three or more. The physical amplification factor (ratio of change in UV-B flux to change in

atmospheric ozone concentration) is calculated to be (negative) two. The ozone depletion is presently estimated to reach an equilibrium level ranging from 2 to 20 percent. The overall amplification factor can be in the range from 2 to greater than 6. The resulting effect to skin cancer rates can range from 4 to greater than 120 percent. Therefore, it is important to more accurately quantify this cause-effect or dose-response relationship for both melanoma and nonmelanoma skin cancer types.

The U.S. basic cancer incidence reporting program, which includes melanoma skin cancer, will be augmented by a special one-year effort beginning in April 1977. This effort will investigate nonmelanoma skin cancer at different latitudes, and therefore different UV fluxes, with reporting from selected U.S. cities or regions. This reporting will include skin types and life-style parameters. Discussions with some other nations are in progress to extend this reporting to the necessary international scope.

3.2 Possible Effects of Increased UV-B on Biological Systems Other Than Human

The objective of the nonhuman biological effects research program is to assess the impact of UV-B radiation on terrestrial and aquatic organisms, especially those used for the production of food, and to determine the ecological significance of increased UV-B radiation.

Terrestrial studies include assessing the effect of increased UV-B exposure on:

- Plant growth and development and key physiological processes such as photosynthesis and respiration.

o production of selected economically important agricultural and forage crops and forest tree seedlings

o stability of agricultural chemicals (fertilizers and pesticides)

o the agricultural ecosystem level (livestock)

o insects, pathogens and their interaction with plants.

Terrestrial studies are being conducted in the laboratory in controlled plant growth chambers, in greenhouses, and in the field utilizing enhanced UV-B radiation from artificial sources.

Aquatic studies include the UV-B tolerance of aquatic organisms and ecosystems; for example, determining the sensitivity of eggs and larvae of commercially important marine species and the sensitivity and activities of surface living organisms (neuston). An important study concerns the influence of UV-B irradiation on N_2-fixation by blue-green algae, which are an essential link in the aquatic food chain and known to be highly dependent on solar radiation for growth.

3.3 Instrumentation Research

Meaningful biological research in the UV-B region requires controllable radiation sources specific to this region (280-320 nm) and instrumentation for measuring the radiation flux over narrow bands in this region. Due to the almost total unavailability of such essential instrumentation specific for the UV-B spectral region, research is being conducted to fulfill those requirements.

Specifically, present research and development aims at improving and standardizing radiation sources in the UV-B region for use in biological effects experiments, constructing a portable spectroradiometer for field use, and developing a laboratory precision spectroradiometer to serve as a standard for calibrating detectors and sources. Workshops have been held to bring biologists and instrumentation experts together to discuss research methodologies and techniques.

3.4 Possible Effects of Ozone Diminution on Climate

Ozone diminution may threaten changes in the climate of the stratosphere and the earth's radiation characteristics. These changes may result in alteration in the earth's tropospheric climate. The potential adverse effects on man and the biosphere by inadvertent modification of the stratosphere is a global problem that deserves serious attention on an international scale.

Investigations are being organized to approach the questions of the direction of possible resulting climate change, the extent, the timing, and the geographic distribution of change. One perspective-setting question concerns the relative magnitude of possible climate change from stratospheric modification and from radiation balance change associated with tropospheric accumulation of constituents such as CO_2 and CFM's.

An earlier section of this paper addressed the U.S. activities for obtaining new information on the climate of the stratosphere, its physical, chemical, and optical properties. As one unique aspect of the developing U.S. Climate Program Plan, plans are being developed to increase the capability to observe a broad variety of parameters

on many scales from satellite altitudes to provide much of the upper atmosphere data required for climate research, particularly with regard to ozone and aerosols.

Because of the interconnections and complex feedback effects of the climatic system (sun, stratosphere, troposphere, hydrosphere, cryosphere, and biosphere), the stratospheric climate cannot be studied in isolation. The effects of stratospheric perturbations must be examined as they appear throughout each of the climate elements. The key to understanding the climatic system, and thus answering these questions, lies in the development of models that simulate the dynamics of the real system.

Numerical general circulation models are currently being studied at several laboratories. Less detailed models, including highly parameterized numerical models and statistically and empirically based models are also under study in several U.S. institutions and agency laboratories.

Existing modeling efforts benefit from empirical studies of the extent and causes of climate variability, which often yield the first estimate of the relative influences of the elements and processes affecting climate change. These diagnostic approaches to climate research are carried out on a small scale throughout university and government laboratories. Development of these empirical studies is seen as a necessary first step in improving our understanding of how the climate system works and how it is evolving. In recognition of the importance of these studies, new

support has been directed to diagnostic techniques, coordination of ongoing related research, and to implementation of plans for expansion.

An adequate data base is needed in all modeling attempts—to test sophisticated numerical models, to provide a basis for empirical studies, and to make actuarial assessments of climate change and impact on food production. Paleoclimate information is assembled and analyzed. The largest of these efforts, the Climate/Long Range Investigation Mapping and Prediction (CLIMAP) program provides information on global temperature through analysis of deep-sea sediment cores. Instrumented records of climate since the mid-16th century are available and archived in World Data Centers. Other major sources of climatic data in the United States are maintained by several agencies. A U.S. Climate Program Plan calls for a major expansion of data management capabilities to accommodate increased research activities in climate.

3.5 Possible Economic and Social Effects of Ozone Diminution and its Control

The United States is examining the economic and social impacts of the biological and physical response mechanisms associated with perturbations in the stratosphere. Any change in man's climate and environment is likely to lead to a change in man's activities since many of these activities depend on climate and environment. The social costs accompanying these changes is the difference in value of production before and after the environmental changes plus any costs incurred during this transition.

This research will attempt to address the socioeconomic considerations for evaluating the terrestrial impacts of stratospheric ozone reduction. Principal emphasis will be the impact of environmental change on agriculture and ecology, human behavior, i.e., changes in clothing, fuel consumption, etc., materials weathering and marine resources. In order to evaluate these impacts the research results on climate variables, temperature changes and ultraviolet radiation will be used as inputs into this assessment.

The ultimate measurement of socioeconomic impacts is difficult to conceptualize and then convert to common units of measure. However, the results of this research will give environmental decisionmakers order of magnitude estimates on the costs associated with changes in climate and ultraviolet radiation from stratospheric ozone reductions.

In view of the present concern in the United States over the impacts of releases of CFM's, it is necessary to examine the economic impacts of regulation on the chemical manufacturers and the aerosol industry. In this regard the United States has undertaken an extensive study to examine the impact of possible aerosol regulations. We have been cooperating with the industry trade associations, the chemical firms and the aerosol fillers and marketers to assure that we are using the most up-to-date financial, engineering and product substitution data. If and as consideration of regulation of other ozone destroying substances becomes advisable, similar assessments will be necessary in relation to the affected industry.

4. Concluding Remarks

In this paper we have indicated the investigations that are now on-going or planned in the United States to understand and evaluate the potential threat of stratospheric ozone diminution. Unfortunately, the investigations which have been already provided for do not include all the investigations which are needed for the above purpose. A full picture of all the investigations required is emerging as this meeting proceeds. As the meeting continues, we look forward to further discussion to identify a consensus evaluation concerning the priority of investigational needs which are not yet provided for, and effective mechanisms for concerned nations and international bodies to join in providing for meeting those needs.